

# International Space Station USOS Potable Water Dispenser Development

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## ABSTRACT

The International Space Station (ISS) Russian Segment currently provides potable water dispensing capability for crewmember food and beverage rehydration. All ISS crewmembers rehydrate Russian and U.S. style food packages from this location. A new United States On-orbit Segment (USOS) Potable Water Dispenser (PWD) is under development. This unit will provide additional potable water dispensing capability to support an on-orbit crew of six.

The PWD is designed to provide incremental quantities of hot and ambient temperature potable water to U.S. style food packages. It will receive iodinated water from the Fuel Cell Water Bus in the U.S. Laboratory element. The unit will provide potable-quality water, including active removal of biocidal iodine prior to dispensing. A heater assembly contained within the unit will be able to supply up to 2.0 liters of hot water (65 to 93°C) every thirty minutes. This quantity will allow three to four crewmembers to rehydrate their food and beverages from this location during a single meal. The unit is designed to remain functional for up to ten years with replacement of limited life items such as filters. It will be the size of two stacked Shuttle Middeck lockers (approximately the size of two small suitcases) and integrated into a science payload rack in the U.S. Laboratory element.

Providing potable-quality water at the proper temperature for food and beverage reconstitution is critical to maintaining crew health and well-being. The numerous engineering challenges as well as human factors and safety considerations during the concept, design, and prototyping are outlined in this paper.

## INTRODUCTION

The galley system for the ISS USOS has changed significantly since it was first conceptualized as a part of Space Station Freedom. The initial concept comprised two full standard racks and included a water dispenser, dual microwave/convection/conduction ovens, a trash compactor system, a handwash, and an integrated food stowage system [1]. To meet the volume constraints created by removal of the U.S. Habitation Module, the USOS galley has been significantly down-sized and will be placed in the U.S. Laboratory Module. It will consist of co-located individual components, including a refrigerator, two briefcase-sized food warmers, and a potable water dispenser.

The ISS Russian Segment has provided potable water dispensing capability for the ISS since it was first inhabited in 2000. The Russian system has been shown capable of providing enough water for at least three crewmembers [2,3]. To increase the ISS crew complement to six, the U.S. must provide potable water dispensing capability for the additional three crewmembers. The subject of this paper is the development of the ISS USOS Potable Water Dispenser (PWD).

## MAJOR ISS PWD REQUIREMENTS

The ISS PWD's primary requirement is to provide potable water for the rehydration of U.S. food packages during meal and snack preparation. The PWD is required to provide accurate incremental volumes (25 to 250 mL in 25 mL increments) of hot and ambient temperature potable water. Iodinated water will be received from the Fuel Cell Water Bus in the U.S. Laboratory. Note: Fuel Cell Water Bus is a misnomer in this case. This bus was originally designed to receive water directly from the Shuttle water system, which receives its water as a byproduct of the Shuttle's fuel cell

power generation system. The Fuel Cell Water Bus is instead connected to the Potable Water Bus and is fed from the Water Processing Assembly (WPA). The PWD is required to provide potable-quality water, including active removal of biocidal iodine prior to dispensing. A heater assembly contained within the unit is required to supply at least 1.5 liters of hot water (65 to 93°C) every thirty minutes. It is desirable for the system to provide up to 2.0 liters of hot water within this same time period. This quantity will allow three to four crewmembers to rehydrate their food and beverages from this location during a single meal. The unit will launch soft-stowed in the Multi-Purpose Logistics Module. It is required to remain functional for up to ten years with replacement of limited life items such as filters. The allowable volume is that of two stacked Shuttle Middeck lockers (approximately the size of two small suitcases), and the unit is required to be integrated into a science payload rack [4,5]. The PWD is shown in Figure 1. The layout of the system's front panel is explained below.

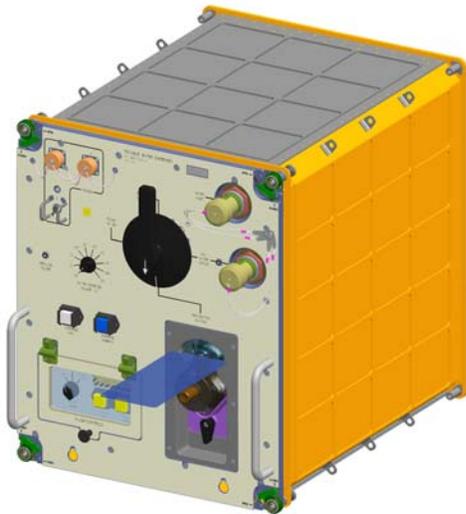


Figure 1. ISS Potable Water Dispenser without electrical and mechanical connections (shown with blue mocked up food package installed)

## GENERAL DESIGN APPROACH

Much experience has been gained dispensing potable water for crew consumption in microgravity during previous spaceflight programs. The majority of this experience has been with the repackaged Space Shuttle galley, which has been in use since 1991 [6]. The approach for development of the PWD was to use as much of the Shuttle galley design and experience as possible.

Extensive knowledge can be drawn from the years of experience with wetted materials exposed to iodinated water. Many of the materials used in the Shuttle galley will be used in the PWD. The most notable of these materials is 316L corrosion resistant stainless steel, which has proven its ability to maintain potable water quality during long-term exposure to iodinated and deiodinated water. The majority of the PWD wetted

components will be made of this material. However, 316L has been shown to adsorb the biocidal iodine present in the U.S. water supply system [7]. Because the PWD will be used multiple times each day and will not sit stagnant for extended periods, the biocidal iodine will be replenished frequently thus maintaining effective microbial levels within the system.

The PWD uses the standard U.S. style food package rehydration interface as used on the Shuttle and ISS. The packages contain a soft silicone septum that must be penetrated by a 3.2mm (0.13-in) diameter rehydration needle. Further, the Shuttle galley successfully included a food package capture device that aids the crew in properly installing food packages. A similar approach will be implemented in the PWD and the design is discussed in more detail below.

Although iodine is an effective biocide, some humans are metabolically sensitive to it. Consequently, iodine removal hardware was developed for use with the Shuttle galley. Removal of the iodine present in the ISS supply water will be accomplished using the same hardware as used with the Shuttle galley. This hardware, the Activated Carbon/Ion Exchange (ACTEX) filter has successfully proven its ability to deiodinate U.S. potable water with an iodine concentration of 6.0 mg/L down to less than 0.2 mg/L [8]. However, unlike on Shuttle where the ACTEX filter is external to the system, the "deiodination filter" will be integrated into the PWD system.

Lessons learned from the Shuttle galley will also be included in the PWD design. The Shuttle galley includes two positive displacement recirculation pumps to aid in proper dispensing temperature and volume. The recirculation pump motors have shown acceptable cycle life, but a few have required replacement in the seventeen years since the Shuttle galley fleet has been in use. Also, the supply water inlet to the Shuttle galley includes flow restrictors to limit the rate of water entering the unit. These restrictors were added to avoid removing too much water from the Shuttle water tanks too quickly. The restrictors are upstream of the recirculation pumps, which thus limits the flow of water into the pumps. This flow limiting requires additional suction pressure from the pump and has been shown to cause dissolved gas to evolve from solution. Shuttle crews have complained that dispensed water can contain excessive free gas.

Additionally, the pumps have been linked to inaccurate dispense volumes. During a large dispense (up to 235 mL on Shuttle), the recirculation pumps gain significant momentum as compared to the momentum during a smaller dispense. This results in a slightly higher average dispense flow rate during a large dispense. When the control system commands the pumps to turn off and the solenoid valves closed, up to ten percent excess water can be dispensed.

The PWD design, shown in Figure 2, has avoided pumps and relies solely on supply pressure to dispense water. This approach saves the mass and volume of a pump, avoids the need for an overpressure relief system, reduces the complexity of the system, and should allow higher dispense accuracy across the full range of volumes. The removal of the pump also eliminates an Orbital Replacement Unit (ORU) and will reduce the amount of maintenance needed for the system over its ten year life.

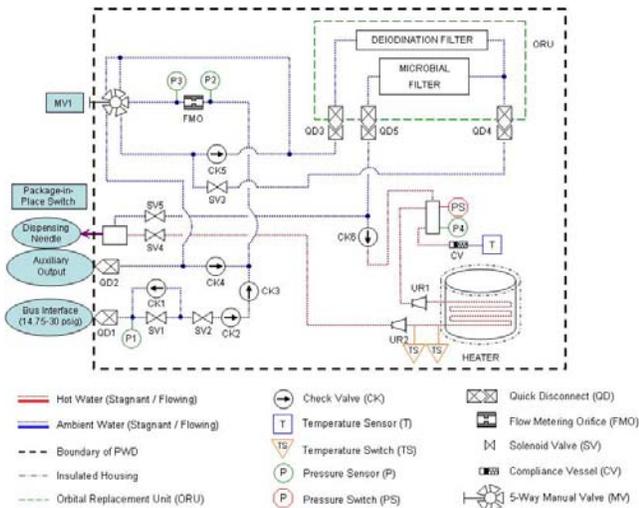


Figure 2. PWD Flow Diagram

Figure 2 illustrates the flow of water through the system. Under normal operation, water enters at Quick Disconnect (QD) 1 at the lower left, then through two solenoid valves and two check valves. The redundancy of these components is related to failure tolerance and is explained below. Water then flows through the flow-metering orifice, whose function is explained in the next paragraph. While in normal dispensing mode, water travels through the upper left port of the manual valve and then into the Filter ORU through QD3. Inside the ORU, water travels through the deiodination filter, through the microbial filter, and then out of the ORU. If an ambient dispense is selected, water travels through an additional solenoid valve and then is dispensed out of the needle. If a hot dispense is selected, water travels into the heater assembly, then through an additional solenoid valve and is dispensed out of the needle.

An additional lesson learned from Shuttle galley experience relates to the method for dispense metering. The Shuttle galley control system is programmed to activate the pumps and open the solenoid valves for a set time interval for each dispense volume increment. If the supply pressure varies, or if the pumps run faster or slower than normal, an inaccurate dispense can occur. The system was designed this way because the Shuttle water supply system has a fairly constant pressure of 138 kPa (gauge). In contrast, the ISS Fuel Cell Water Bus pressure can vary between 103 and 207 kPa (gauge). To accommodate this range, the PWD approach actively measures the system's flow rate and

calculates the time the solenoid valves should remain open for each dispense volume increment. The flow rate is determined by measuring the pressure drop created over a fixed diameter orifice. This pressure drop is proportional to the flow rate, which is then utilized to calculate how long the solenoid valves must remain open. Testing results of a prototype system, shown in Table 1, prove the design meets the required dispense accuracy for the PWD. The system pressure was varied over the full range to ensure accuracy at all fluid interface conditions.

Table 1. Prototype Dispense Accuracy Testing Results

Target Volume (mL)	Allowable Error (%)	Measured Error (%)
25	20	12
50	20	4
75	13	3.3
100	10	2
125	10	1
150	10	1.3
175	10	1.7
200	10	2.5
225	10	2.2
250	10	3.6

## FREE GAS CONSIDERATIONS

The PWD heater assembly is designed with two concentric, coiled stainless steel tubes wrapped with thermostatically controlled heater strips as shown in Figure 3. This design precludes superheating of the liquid at the heated surfaces, which reduces microgravity-induced nucleate boiling and thus reduces the generation of free gas. The selected 19mm (0.75-in) outer tube diameter creates a consistent heating profile along the radius of the tube and creates plug flow conditions which force hot water out as ambient water enters. The design requires ambient water remain resident in the heater assembly for approximately 20 minutes to reach the proper dispense temperature (65 to 93°C). Although the design is not optimal for weight or volume, it meets or exceeds the integrated set of PWD requirements while maintaining minimal system complexity.

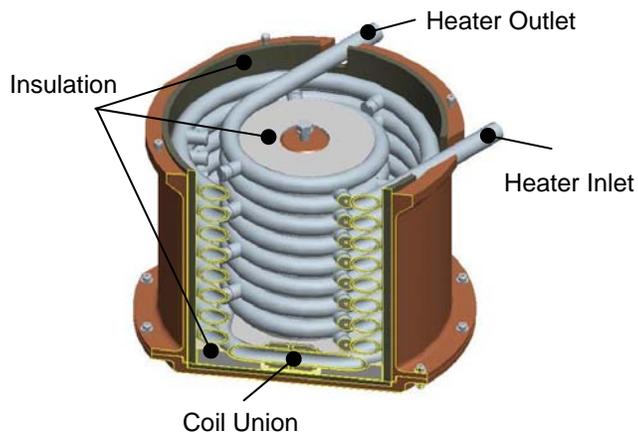


Figure 3. Heater Assembly

An additional consideration is placement of the deiodination and microbial filters with respect to the heater assembly. The supply water is void of free gas (at 101 kPa (absolute) and 37°C), but saturated with dissolved oxygen from the WPA catalytic oxidation reactor [9, 10]. Analyses estimate approximately 2.3% free gas by volume will evolve from solution when this water is heated from 18°C to 93°C. The microbial filter is a hydrophilic depth filter with a pore size of 0.2 microns. This filter is highly sensitive to free gas and will trap and allow coalescence of bubbles until the filter is blocked, precluding further dispensing from the system. Due to these sensitivities, the filters were placed upstream of the heater system to avoid exposure to free gas as shown in Figure 2. Additionally, these filters are ORUs to enable their replacement if free gas exceeds the supply water inlet requirements.

## SAFETY CONSIDERATIONS

ISS safety requirements dictate systems be designed with two fault tolerance against a catastrophic hazard. Catastrophic hazards are those which can lead to loss of life or loss of the ISS. Due to its danger to ISS electronics and the possibility of a crewmember's inadvertent inhalation, leakage of more than 3.8 liters of water into the ISS cabin has been deemed a catastrophic hazard. Therefore, the PWD has been designed to be two fault tolerant against leakage. As shown in Figure 2, the system contains at least three solenoid valves between the supply water bus and the dispensing needle. At least one of these solenoid valves must close to stop flow of water from the supply bus. The control system is designed to command all valves closed following a dispense. If the main controller should fail to command the valves closed, two independent "watchdog" timers will take control and command the valves closed. Only one of these control devices is needed to preclude continual dispensing from the rehydration needle. An additional control against leakage is the package-in-place switch which prevents dispensing when a food package is not installed. This will prevent inadvertent dispensing if the PWD is bumped by crewmembers or equipment translating

through the U.S. Laboratory module. It will also cease dispensing if the food package is removed prematurely.

Fire in the cabin is another catastrophic hazard that must be triply controlled. The PWD heater assembly contains high temperature (up to 93°C) resistive heater strips that could continue to increase the temperature inside the heater assembly if they were to remain active. In this scenario, the high temperature of the heater strips is considered an ignition source and thus must be controlled to be two fault tolerant. Each heater circuit (consisting of three heater strip pieces) is controlled with three independent thermostats (set points up to 93°C). Only one of these thermostats is needed to deactivate the heater circuit.

An additional catastrophic hazard is back-contamination of the ISS Fuel Cell Water Bus. Other users of this bus, such as the very critical Oxygen Generation System, are susceptible to contaminated water. To protect against back contamination, the PWD contains dual check valves near the inlet from the supply water bus. Further, the system's wetted materials have been selected to preclude chemical contamination of the water. Thirdly, the system contains a microbial filter which, along with the iodinated water contained in the supply water, will prevent back-contamination from the food packages or from system use by the crew.

An additional safety feature related to water contamination is inclusion of a "flush mode" which allows the crew to flush the entire system with iodinated water. If microbial overgrowth should occur in the deiodinated portions of the system, the ability to iodinate the system should effectively remediate this growth. Chemical and microbial potable water samples will be taken from the PWD monthly to ensure that the water being dispensed is of the proper quality for crew consumption. If an above specification condition is detected in the microbial sample, the flush mode will be employed. The iodinated water flush is accomplished by bypassing the deiodination filter contained within the Filter ORU. As shown in the flow schematic in Figure 2, instead of water flowing into QD3 as it does during a nominal dispense, water would flow into QD4, then through the microbial filter, and out of the ORU.

## HUMAN FACTORS CONSIDERATIONS

As a part of the USOS galley, the PWD will be used by the crew multiple times each day. Consequently, it is essential that PWD usage be intuitive and simple. Similar to the Shuttle galley, the PWD includes a device, called the "rehydration station" (shown in Figure 4), which aids the crew in the proper and consistent installation of a food package onto the rehydration needle. It also contains the package-in-place switch as mentioned above. The rehydration station requires single-handed actuation while the second hand is used to place the food package. This is accomplished by grasping the disk handle with the index and middle fingers while the button is pressed with the thumb.

Pressing the button lowers a slide which opens the port for insertion of the food package. Releasing the button results in the device capturing the package and placing it in the proper orientation. Following capture, the entire assembly is inserted onto the rehydration needle. Following dispense, the package is removed by grasping the disk handle, sliding the assembly off the needle, and pressing the button which releases the food package. This device was redesigned for use in the PWD. The Shuttle galley version required too much space inside the system to meet ISS PWD volume requirements. The general use of the rehydration station has been preserved, but the new design has reduced the volume and, subsequently, the weight. The device is not an ORU but is capable of being replaced as a contingency operation. The rehydration needle is an ORU and can be replaced if it becomes damaged or contaminated.

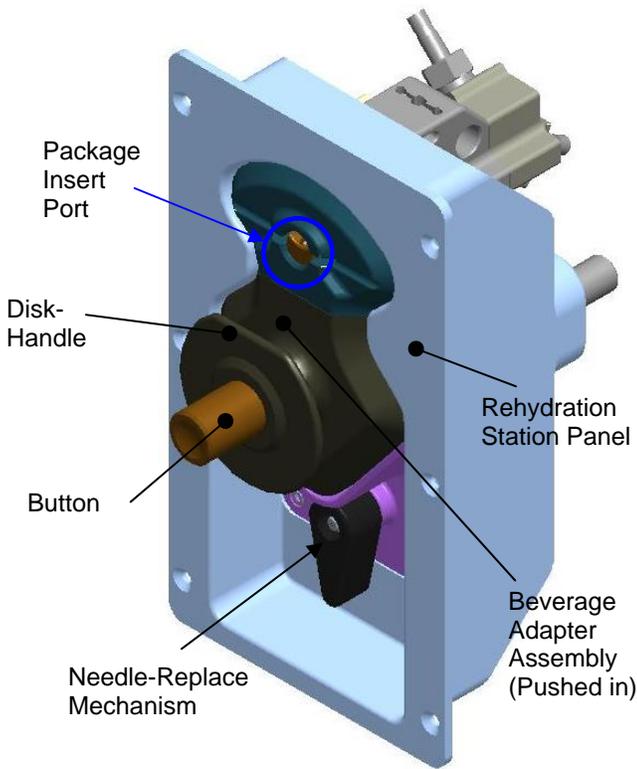


Figure 4. Rehydration Station

The design and placement of the Filter ORU within the system is driven by human factors, accessibility, and ease of replacement. The filters contained within the ORU are consumable items and it is expected that the ORU will need to be changed out approximately once per year. The ORU contains three self-sealing male QD halves which contain the fluid inside the system during replacement. These are contained along a rigid panel as shown in Figure 5. The QDs non-symmetric placement on this panel prevents improper installation of the ORU. The external housing is sized to allow grasping with a single hand.

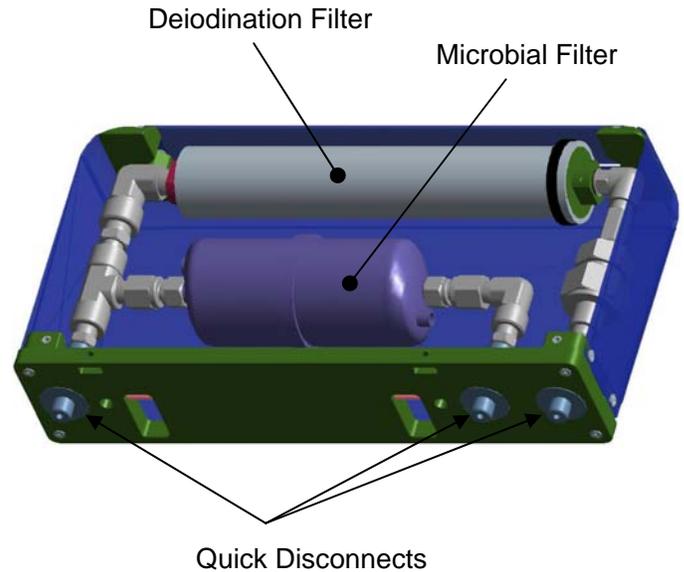


Figure 5. Filter ORU (Near side cover removed)

Removal and installation of the Filter ORU is accomplished by actuation of a latching mechanism. This mechanism uses leverage to reduce the 356 N (80 lbf) of force required to install the three ORU QDs while the system is under maximum pressure to only 32 N (7.5 lbf). The latching mechanism, shown in Figure 6, is also a one-handed operation that involves pressing in a spring-loaded button and then pulling down on the lever, thus releasing latches which hold the ORU in place. Appropriate hand clearance to access this latch handle was considered according to NASA's anthropometric standards [11].

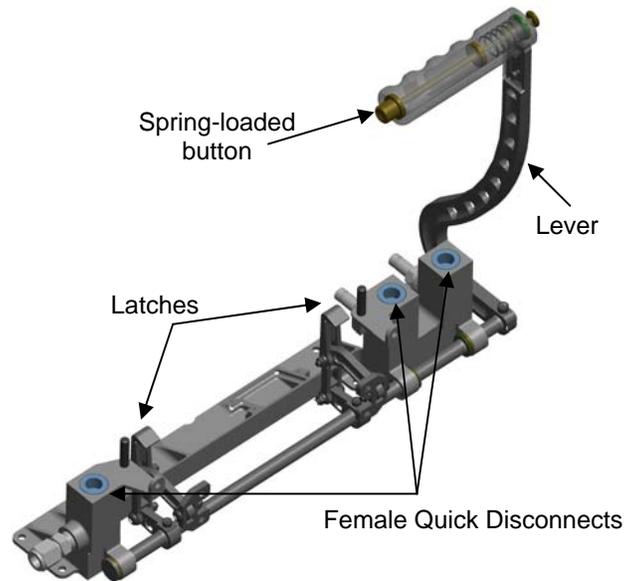


Figure 6. ORU Latching Mechanism

The Filter ORU is located on the left side of the PWD, with access via a removable service panel. Figure 7

shows the PWD with the internal “chassis” extended, the service panel removed, and the ORU latching mechanism in the un-latched position. The Filter ORU is ready to be removed in the configuration shown.

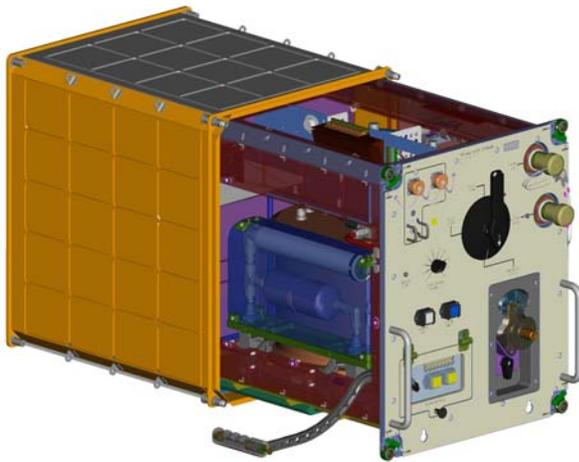


Figure 7. PWD Configuration for Filter ORU Removal

The front panel of the PWD is shown in Figure 8. The layout of the front panel was mainly dictated by the placement of components inside the system. However, it was also dictated by ease of use and human factors. Areas on the front panel are dedicated to related functions. For instance, all dispense controls (dispense quantity and type) are co-located at the center left. The flush dispense controls are located at the lower left. The electrical supply connectors and power on/off switch are located at the upper left. The water inlet QD is located at the upper right. The rehydration station is located at the lower right. And, in the center is the manual valve that allows switching between system modes. The dispense pushbuttons also contain light-emitting diodes (LEDs), which illuminate when the system is ready to dispense. During a dispense, the actuated pushbutton blinks and following the dispense, the LED is extinguished. This provides feedback to the crew on the current state of the system.

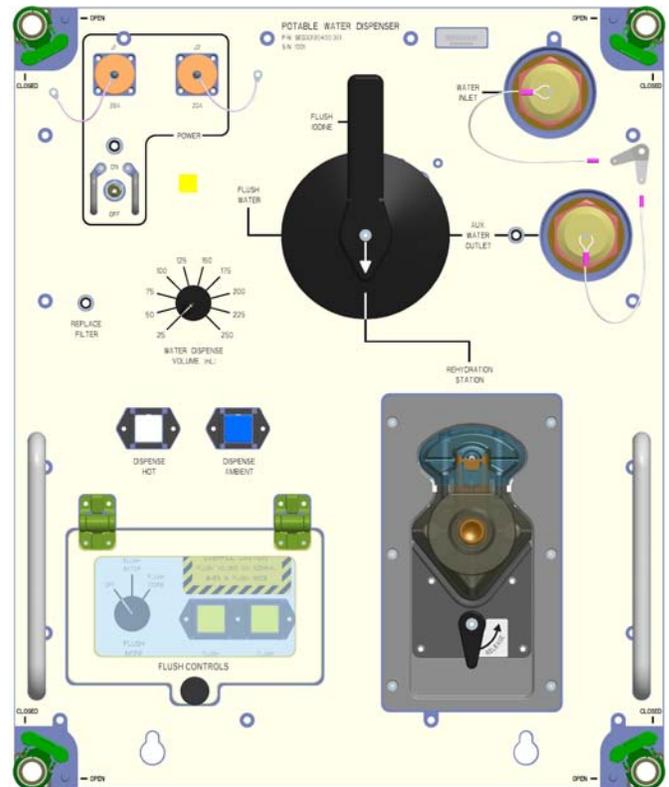


Figure 8. PWD Front Panel

## CONCLUSION

Volume constraints on the ISS have driven the USOS galley system to consist of co-located individual components as opposed to an integrated system as on the Shuttle. The ISS PWD, as a part of this USOS galley system and the sole potable water dispensing system in the USOS, is an essential part of crew habitability. Experience from the Shuttle galley has been extensively incorporated into the PWD design. ISS safety requirements to maintain proper failure tolerance have increased the complexity of the system. Due to its frequent use, ease of use was a major factor in development of the unit and strongly influenced the design of the system. The PWD is planned for launch on STS-126/ULF-2 in late 2008, along with the majority of other U.S. hardware needed to increase the crew complement to six. Testing in microgravity and integrated system level testing has not yet been accomplished. Future papers will describe the use of the system in these environments.

## ACKNOWLEDGEMENTS

The authors would like to thank the PWD development team and NASA community stakeholders for their assistance with development of the PWD and the contents of this paper. The ISS PWD project is funded by the ISS Vehicle Office.

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## ACRONYM LIST

°C	Degrees Celsius
ACTEX	Activated Carbon/Ion Exchange
in	Inch
ISS	International Space Station
kPa	Kilopascals
lbf	Pounds force
LED	Light-emitting Diode
mg/L	Milligrams per liter
mL	Milliliter
mm	Millimeter
ORU	Orbital Replacement Unit
PWD	Potable Water Dispenser
QD	Quick Disconnect
USOS	United States On-orbit Segment
WPA	Water Processing Assembly